APPLICATION OF SOVIET PNE DATA TO THE IMPROVEMENT OF SEISMIC MONITORING CAPABILITY

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ABSTRACT

In order to discriminate the regional seismic signals produced by underground nuclear explosions from those produced by earthquakes, rockbursts, and conventional mining explosions of comparable magnitude, it is necessary to know the ranges of signal variations that can be expected as a function of source type and propagation path conditions over the entire ranges of these conditions which may be encountered in global test monitoring of the Comprehensive Nuclear-Test-Ban Treaty. For this reason, Maxwell Technologies and the Russian Institute for Dynamics of the Geospheres (IDG) have been working on a joint research program to improve regional discrimination capability through analyses of seismic data recorded from Soviet Peaceful Nuclear Explosion (PNE) events. During the past year the effort on this project has continued to focus on discrimination analyses of regional seismic data recorded from Soviet PNE tests and on a comparison of the characteristics of U.S. and Soviet explosion aftershocks. The discrimination research has centered on an analysis of regional seismic data recorded from Soviet PNE tests at both the Borovoye and selected other Soviet stations. Analyses of the Borovoye data have revealed that some of the Soviet PNE tests can't be reliably identified as nuclear explosions using the nominal high frequency L_g/P_n spectral ratio discriminant currently being tested at the IDC. In fact, these Borovoye PNE discriminant values have been found to constitute some of the most anomalous explosion L_g/P_n ratios in the large discrimination database assembled by Fisk (1999). This analysis is currently being extended to incorporate data recorded from 12 Soviet PNE events at a number of temporary stations which were deployed in the 200-700 km distance range from these tests. These high resolution data have been digitized at the IDG and are currently being processed to determine high frequency L_g/P_n discriminant ratio values which can be compared with those determined from data recorded at the Borovoye station, to further test the applicability of this proposed IDC regional discriminant. The analysis of explosion aftershocks has been directed toward an assessment of their potential applicability to onsite inspections under the CTBT. That is, given the existing uncertainties in IDC seismic locations, it will generally be necessary to initially employ a number of monitoring technologies in an attempt to zero in on the event location for onsite inspection purposes, and one of the primary techniques proposed for this purpose is the seismic detection of explosion induced aftershocks by temporary regional stations deployed for that purpose (Zucca et al., 1996). In order for this approach to be useful and reliable, it is necessary to have quantitative understanding of the dependence of aftershock activity on the explosion source characteristics. Most of the current state of knowledge regarding such explosion aftershocks is based on experience with explosions conducted at nominal containment depths at a few U.S. and Soviet nuclear weapons test sites. Thus, it is not clear how representative this experience is for the monitoring of small, deeply buried explosions in the variety of tectonic and geologic environments which must be considered in global monitoring of the CTBT. Aftershock monitoring data recorded from the more diverse Soviet PNE tests can help to supplement these test site data to provide a more extensive experience base for use in defining onsite inspection strategy. Current effort on this phase of the project is directed toward the characterization of aftershock sequences observed following both Soviet PNE and weapons tests at designated test sites. These studies encompass analyses of aftershock information from 15 Semipalatinsk, 10 Novaya Zemlya, and 12 Soviet PNE tests conducted at a variety of locations throughout the FSU.

OBJECTIVES

Under this research program, scientists from Maxwell Technologies, Inc. and the Russian Institute for Dynamics of the Geospheres (IDG) are using seismic data recorded from Soviet Peaceful Nuclear Explosions (PNE) and nearby Central Asian earthquakes and chemical explosions to better define the limitations of existing operational capabilities with respect to the global seismic monitoring required by the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The objectives of this program are to expand our recently completed analysis of regional seismic data recorded from Soviet PNE events to incorporate seismic data from nearby earthquakes and large chemical explosions, and to use these data to directly test the utility of different regional discriminants over the widest possible ranges of source and propagation path conditions.

RESEARCH ACCOMPLISHMENTS

During the past year, work on this project has been directed toward the continuation of the discrimination analysis of broadband seismic data recorded from Soviet PNE events, a comparison of near-regional seismic data recorded from nearby chemical and nuclear explosions at the Soviet Degelen Mountain test site and an analysis of aftershock monitoring data collected following a number of Soviet PNE tests. Figure 1 shows the map locations of Soviet PNE tests for which broadband, digital seismic data have now been collected and analyzed to further evaluate the high frequency (6-8 Hz) Pn/Lg spectral ratio discriminant currently being tested at the PIDC. These data provide a

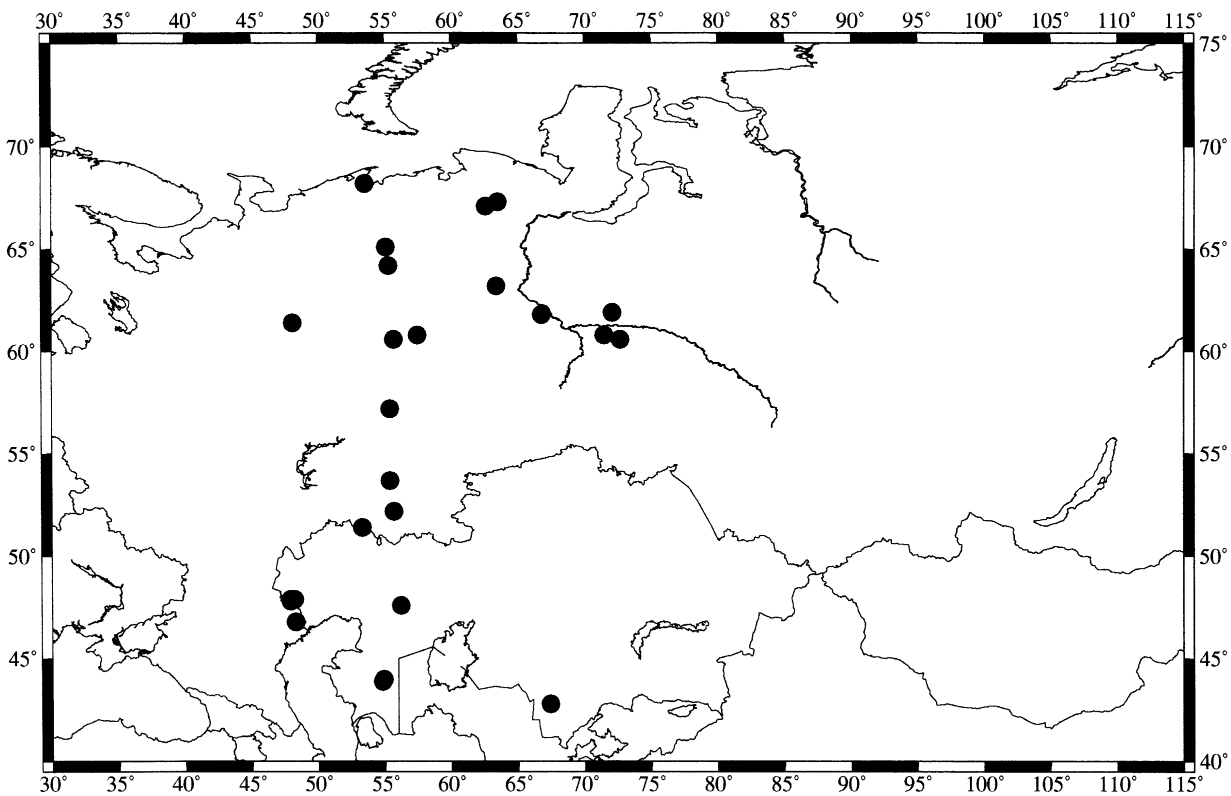

Figure 1. Map locations of Soviet PNE events for which high frequency (6-8 Hz) Pn/Lg spectral ratio discriminant values have been estimated from recorded regional seismic data.

valuable supplement to the previously analyzed nuclear test site data in that they encompass a wide range of source media (salt, limestone, granite, sandstone/shale, clay, chalk) and sample a variety of different regional propagation paths. Moreover, these PNE events are predominantly low yield (average yield = 9 kt), overburied (average scaled depth = 425m/kt$^{1/3}$) explosions of the type which are of greatest concern in CTBT monitoring. The 6-8 Hz Pn/Lg discriminant ratio values determined from broadband regional recordings of these PNE events are plotted in Figure 2, where they are compared with the corresponding mean and 2σ bounds on the REB earthquake population analyzed by Fisk et al (1999). It can be seen that the means of the two populations are well separated, although the two distributions overlap to some extent, as has been noted previously by Fisk et al (1999) in their analyses of data recorded from nuclear explosions at the various weapons test sites. However, several of the Soviet PNE spectral discriminant values shown in Figure 2 constitute the lowest explosion discriminant values observed to date, with values approaching the mean of the REB earthquake population. Preliminary analysis of the geographical distribution of the PNE events contributing these apparently anomalous values suggest that they may be affected by unusual propagation conditions. In any case, these results indicate that the high frequency Pn/Lg spectral ratio discriminant will have to be carefully calibrated for applications at previously untested sites.

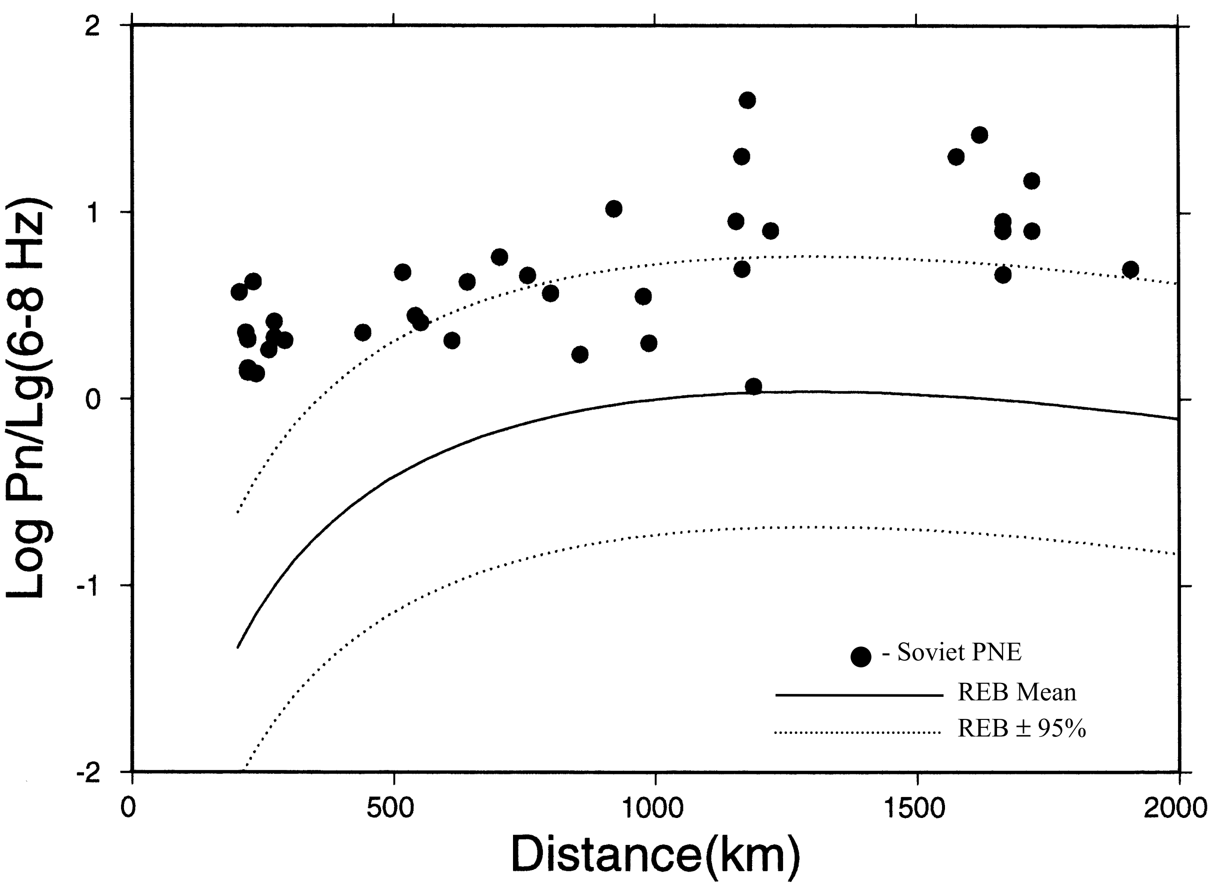

Figure 2. Comparison of 6-8 Hz Pn/Lg discriminant ratio values determined from broadband regional recordings of the Soviet PNE events of Figure 1 with the corresponding mean and 2σ bounds on the REB earthquake population analyzed by Fisk et al (1999).

The analysis of seismic signal generation by chemical (CE) and nuclear (NE) explosions has focused on comparisons of near-regional seismic data recorded from two nearby explosions conducted at the Degelen Mountain area of the Semipalatinsk test site. A sketch showing the relative locations and configurations of these two explosions is shown in Figure 3 where it can be seen that they were separated by less than one kilometer. The CE test was conducted first, on June 5, 1961 and consisted of 150 tons of fully tamped ammonium nitrate detonated in a rectangular chamber. The companion NE test was conducted at nearly the same depth four months later on October 11, 1961 and had a yield of 1.1kt. Broadband seismic data were recorded from both events at stations located at distances of 39 and 84 km from the Degelen site. The vertical component recordings from the two events at the 39 km station are shown in Figure 4 where it can be seen that they are fairly similar, although, as might be expected, the initial P wave arrival from the NE event is more impulsive and simple than that from the CE event. It can be also be seen that the moveout of the Rayleigh wave arrival with respect to the initial P arrival is greater for the NE event than for the CE event, which turns out be consistent with the 1 km separation of the two explosions shown in Figure 3. More surprising is the fact that when this relative delay is accounted for, it can be seen that the two Rayleigh wave arrivals are 180° out of phase, with that from the CE event appearing to be phase reversed with respect to that expected from a nominal explosion source. This phase reversal can also be seen on the 84 km recordings and may indicate that significant tectonic release accompanied the CE event. If this hypothesis is correct, then it may be that there was no significant strain energy remaining to be released by the subsequent, nearby NE event, which could provide a plausible explanation for the relative Rayleigh wave phase reversal between the two explosions.

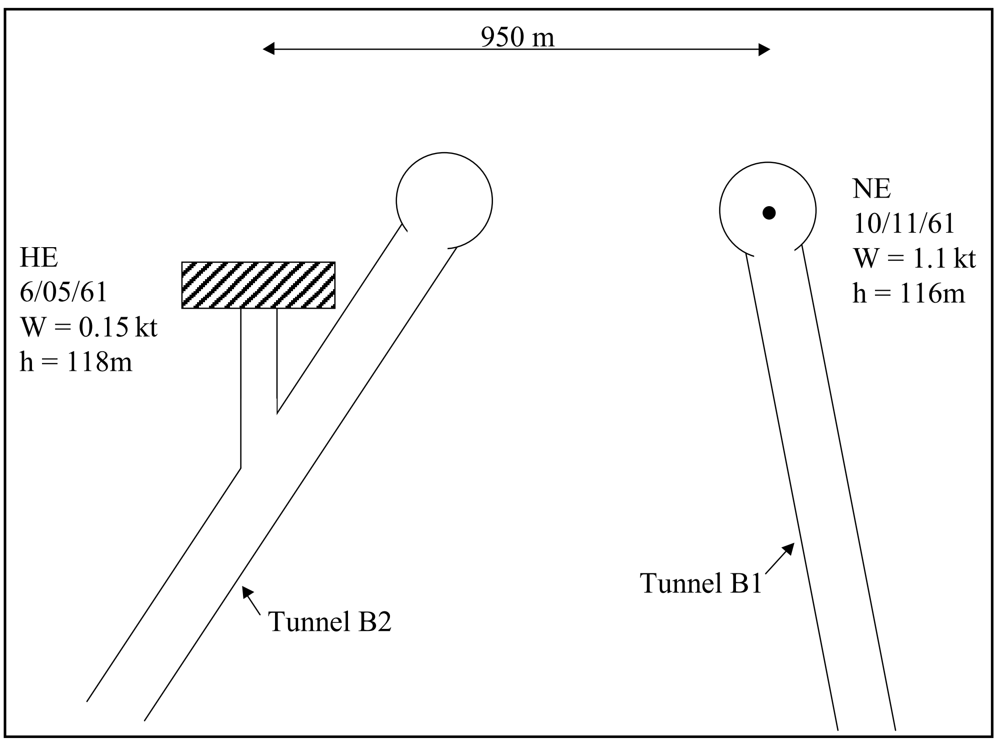

Figure 3. Schematic diagram showing the source configurations for the nearby 150 ton CE and 1.1 kt NE events detonated at Degelen Mountain in 1961.

The average NE/CE spectral ratios determined from the P and S wave time windows, as well as the total vertical component recordings at the 39 and 84 km stations are compared in Figure 5 where it can be seen that they are all roughly independent of frequency over the range from 1 to 20 Hz, with average values ranging from about 7 to 10, which is roughly consistent with the direct ratio of the two yields (i.e. 7.3). Thus, in this case, it does not appear that the seismic coupling of the CE event was greater than that of an NE event of comparable yield by the often quoted factor of two. Moreover, it is surprising that the spectral ratios appear to be independent of frequency in that the nominal source corner frequency of the 1.1 kt NE event is on the order of 5 Hz, while that of the 150 ton CE event

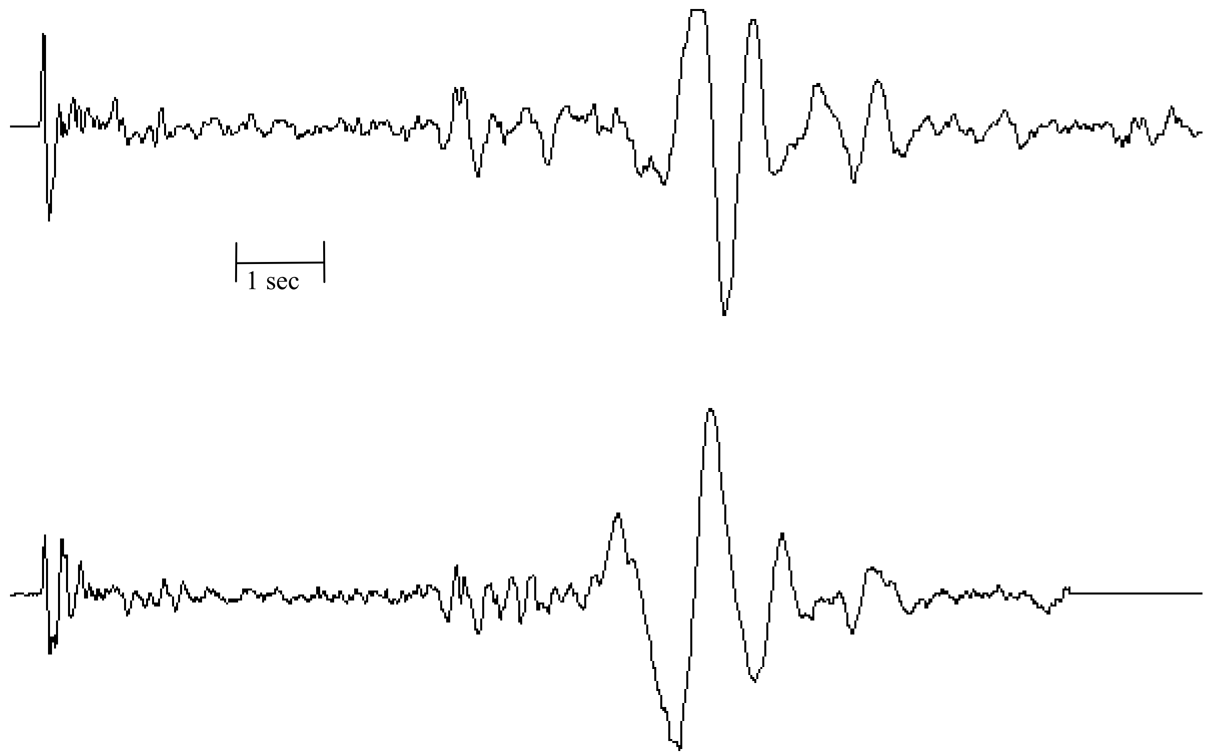

Figure 4. Comparison of vertical component recordings of the Degelen Mountain CE and NE events observed at a near-regional station at a range of 39 km. Note that the Rayleigh wave arrival from the CE event appears to be phase reversed with respect to that from the NE event.

should be approximately a factor of two larger. It follows that, in terms of conventional explosion source theory, the spectral ratios would in fact be expected to decrease significantly between 5 and 10 Hz. Thus, it may be that both the amplitude level and frequency content of the CE seismic source have been affected by tectonic release. It will be necessary to recover and analyze the free-field data recorded from these explosions to conclusively test this hypothesis.

With regard to the third topic of our current research, it is well known that most underground nuclear explosions are followed by aftershocks which can be associated with either the cavity collapse process or with the triggering of tectonic strain release by the explosions. In fact, the detection of such aftershocks is one of the primary techniques proposed for the location of clandestine underground nuclear tests under the onsite inspection regime of the CTBT (Zucca et al, 1996). In order for this approach to be useful and reliable, it is necessary to have quantitative understanding of the dependence of aftershock activity on the explosion source characteristics. Most of the current state of knowledge regarding such explosion aftershocks is based on experience with explosions conducted at nominal containment depths at a few U.S. and Soviet nuclear weapons test sites. Thus, it is not clear how representative this experience is for the monitoring of small, deeply buried explosions in the variety of tectonic and geologic environments which must be considered in global monitoring of the CTBT. Aftershock monitoring data recorded from the more diverse Soviet PNE tests can help to supplement these test site data to provide a more extensive experience base for use in defining onsite inspection strategy. Therefore, an initial sample of 13 Soviet PNE events for which aftershock monitoring was carried out has been selected for analysis. The map locations of these explosions are shown in Figure 6 where it can be seen that they are broadly distributed across the territories of the former Soviet Union. The location symbols on this figure distinguish between those PNE events for which aftershocks were observed and those for which no aftershocks were detected. Note that, in contrast to NTS

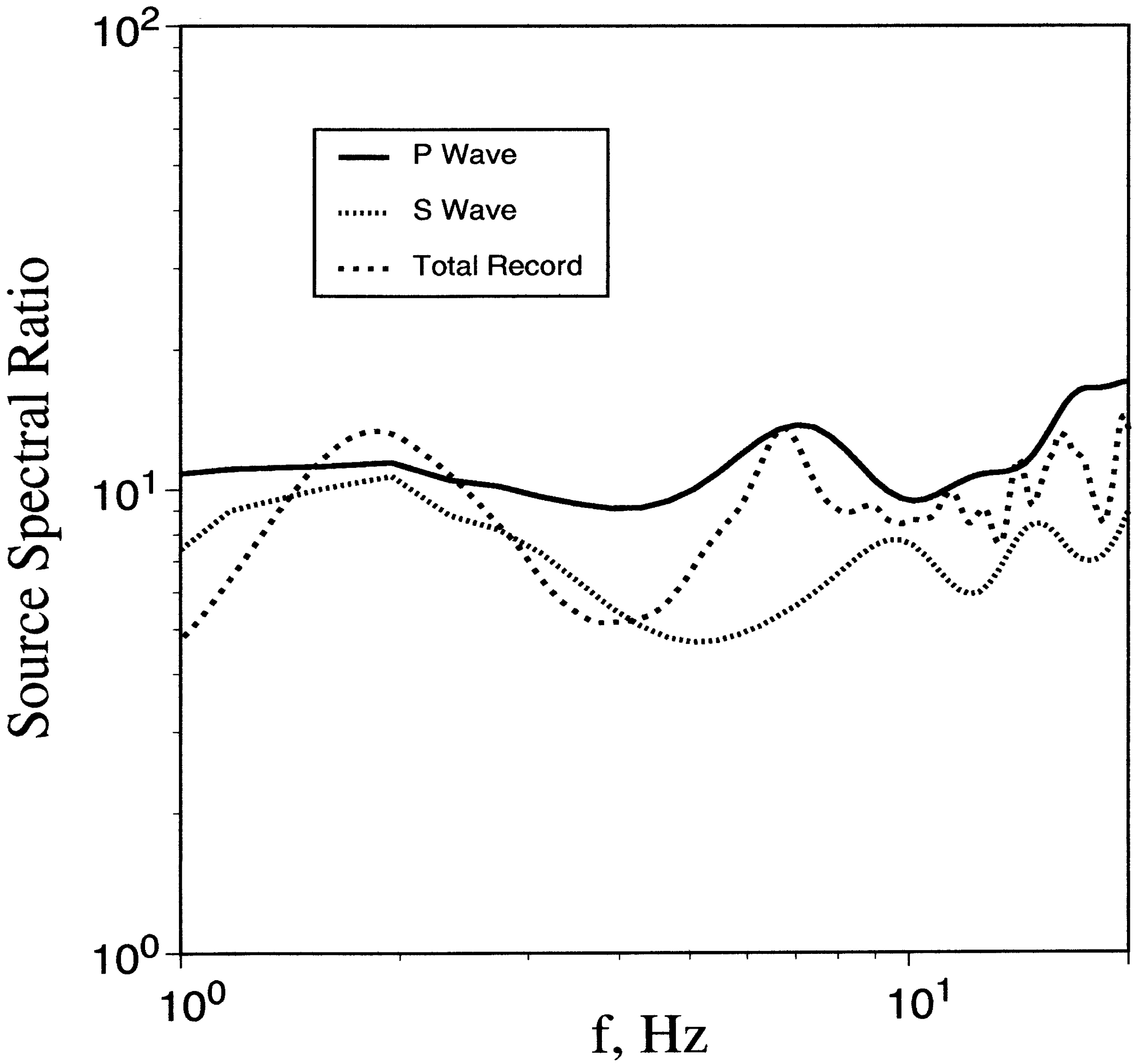

Figure 5. Average Degelen NE/CE source spectral ratios determined from data recorded at the 39 km and 84 km stations.

experience, there are a significant number of Soviet PNE events for which no aftershock activity was detected. The source parameters of these 13 PNE events are listed in Table 1 where it can be seen that the explosions for which no aftershocks were observed encompass a wide variety of source media, yields and depths of burial, although most are significantly overburied relative to the nominal nuclear test site scaled depth of burial criterion. However, the four PNE events of Table 1 for which aftershocks were observed were also low yield, overburied explosions, so these can not be the only factors controlling the occurrence of aftershocks. For each of the four PNE events for which aftershocks were observed, the dependence of aftershock frequency of occurrence and magnitude on elapsed time after the explosion was investigated in detail. It was found that for two of the explosions (Helium-3 and Quartz-4) the aftershock activity ceased completely within 8 hours after the explosion, while those from Ruby-1 ceased within 20 hours and those from Kama-1 ceased within 67 hours. Thus only one of these 13 PNE events triggered aftershock activity which might conceivably have been detected by seismic monitoring associated with an onsite inspection. These results are currently being compared with other observations from nuclear tests at weapons test sites in the U.S. and Former Soviet Union in an attempt to better quantify the probability of their detection under a CTBT onsite inspection regime.

Table 1. Source Parameters of Soviet PNE Events Analyzed For Explosion-Induced Aftershocks

Aftershocks Observed

DATE	NAME	LAT, N	LON, E	YIELD, kt	h, m	EDIUM
7/08/74	Kama-1	53.7	55.1	10	2123	limestone
9/17/84	Quartz-4	55.8	87.5	10	557	granite
4/19/87	Helium-3	60.6	57.2	3.2	2015	limestone
9/06/88	Ruby-1	61.4	48.1	7.5	793	anhydrite

No Observed Aftershocks

DATE	NAME	LAT, N	LON, E	YIELD, kt	h, m	EDIUM
12/06/69	Mangyshlak-1	43.9	54.8	31	407	chalk
6/25/70	Magistral	52.2	55.7	2.3	702	salt
12/12/70	Mangyshlak-2	43.8	54.9	85	497	chalk
12/23/70	Mangyshlak-3	44.0	54.9	75	740	clay
12/22/71	Azgir 3-1	47.9	48.1	64	986	salt
4/11/72	Crater	37.3	62.1	14	1720	limestone
9/30/73	Sapphire-2	51.7	54.6	6.6	1145	salt
8/10/77	Meterorite-5	51.0	111.0	8.5	494	granite
9/10/77	Meterorite-4	44.0	54.9	75	740	clay

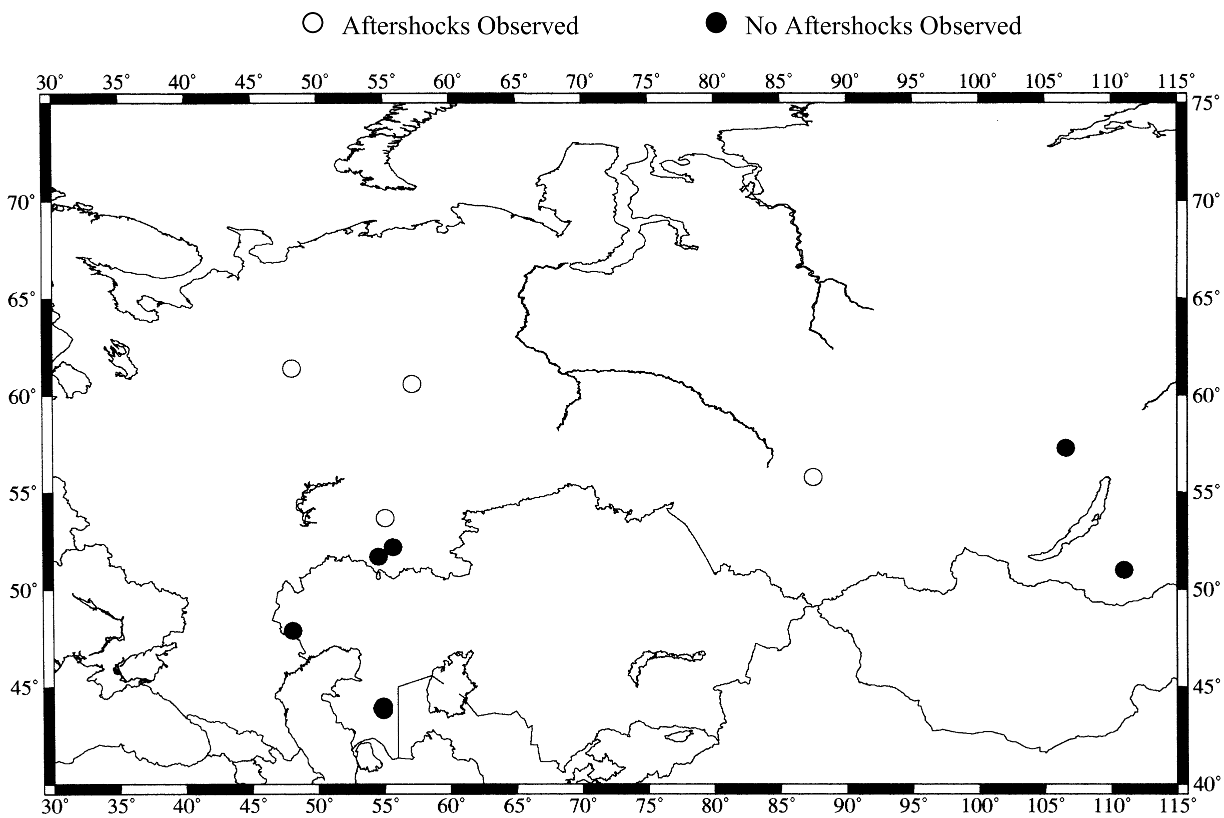

Figure 6. Map locations of Soviet PNE events for which onsite monitoring for aftershock activity was carried out.

CONCLUSIONS AND RECOMMENDATIONS

A three year study has now been completed in which data recorded from Soviet PNE events have been analyzed to assess their implications with respect to the identification of clandestine underground nuclear tests under the CTBT. A seismic source summary for Soviet PNE events has been published (Sultanov et al, 1999) which lists the best currently available source parameters for 122 PNE experiments conducted between 1965 and 1988. In addition, broadband regional seismic data recorded from a number of these PNE events and nearby earthquakes at the Borovoye station and other temporary stations have been systematically analyzed to quantify regional discrimination capability with respect to such events. The results of these analyses have indicated that, while the conventional high frequency S/P discriminants generally separate these explosion and earthquake populations, there is evidence that additional research will be required before low yield, overburied explosions in hardrock media can be consistently identified with high confidence using such discriminants. A comparison of near-regional seismic signals recorded from nearby CE and NE events at Degelen Mountain has also been completed and evidence has been found which indicates that tectonic release may also affect the seismic source characteristics of CE events, further complicating the seismic discrimination of these two types of tamped underground explosions. Finally, the results of near-field aftershock monitoring of a number of Soviet PNE events have been reviewed and it has been found that a surprisingly large number either produced no detectable aftershocks or produced brief aftershock sequences which ceased within 20 hours after the explosion. Such experience will have to be considered in evaluations of the reliability of aftershock monitoring to identify clandestine underground nuclear test locations during possible onsite inspections under the CTBT.

Key Words: seismic, discrimination, regional, Soviet PNE, Borovoye, aftershocks

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